

Tungsten

Tungsten, or **wolfram**,^{[9][10]} is a [chemical element](#) with the [symbol](#) **W** and [atomic number](#) 74. Tungsten is a [rare metal](#) found naturally on Earth almost exclusively as compounds with other elements. It was identified as a new element in 1781 and first isolated as a metal in 1783. Its important [ores](#) include [scheelite](#) and [wolframite](#), the latter lending the element its alternate name.

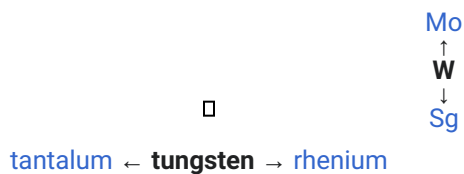
Tungsten, $_{74}\text{W}$



Tungsten

Pronunciation	/ˈtʌŋstən/ (<i>TUNG-stən</i>)
Alternative name	wolfram, pronounced: /ˈwʊlfrəm/ (<i>WUUL-frəm</i>)
Allotropes	α-tungsten (common), β-tungsten
Appearance	grayish white, lustrous
Standard atomic weight <i>A</i>_r[∘](W)	183.84 ± 0.01
	183.84 ± 0.01 (abridged) ^[1]


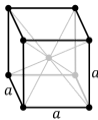
Tungsten in the periodic table



Atomic number (Z)	74
Group	group 6
Period	period 6
Block	d-block
Electron configuration	[Xe] 4f ¹⁴ 5d ⁴ 6s ²
Electrons per shell	2, 8, 18, 32, 12, 2

Physical properties

Phase at STP	solid
Melting point	3695 K (3422 °C, 6192 °F)

Boiling point	6203 K (5930 °C, 10706 °F)					
Density (near r.t.)	19.25 g/cm³					
when liquid (at m.p.)	17.6 g/cm³					
Heat of fusion	52.31 kJ/mol ^{[3][4]}					
Heat of vaporization	774 kJ/mol					
Molar heat capacity	24.27 J/(mol·K)					
Vapor pressure						
<i>P</i> (Pa)	1	10	100	1 k	10 k	100 k
at <i>T</i> (K)	3477	3773	4137	4579	5127	5823
Atomic properties						
Oxidation states	−4, −2, −1, 0, +1, +2, +3, +4 , +5, +6 (a mildly acidic oxide)					
Electronegativity	Pauling scale: 2.36					
Ionization energies	1st: 770 kJ/mol 2nd: 1700 kJ/mol					
Atomic radius	empirical: 139 pm					
Covalent radius	162±7 pm					
						
Spectral lines of tungsten						
Other properties						
Natural occurrence	primordial					
Crystal structure	body-centered cubic (bcc)					
						
Speed of sound thin rod	4620 m/s (at r.t.) (annealed)					
Thermal expansion	4.5 μm/(m·K) (at 25 °C)					
Thermal conductivity	173 W/(m·K)					

Electrical resistivity	52.8 nΩ·m (at 20 °C)			
Magnetic ordering	paramagnetic ^[5]			
Molar magnetic susceptibility	+59.0 × 10 ^{−6} cm ³ /mol (298 K) ^[6]			
Young's modulus	411 GPa			
Shear modulus	161 GPa			
Bulk modulus	310 GPa			
Poisson ratio	0.28			
Mohs hardness	7.5			
Vickers hardness	3430–4600 MPa			
Brinell hardness	2000–4000 MPa			
CAS Number	7440-33-7			
History				
Discovery and first isolation	Juan José Elhuyar and Fausto Elhuyar ^[7] (1783)			
Named by	Torbern Bergman (1781)			
Symbol	"W": from <i>Wolfram</i> , originally from Middle High German <i>wolf-rahm</i> 'wolf's foam' describing the mineral wolframite ^[8]			
Main isotopes of tungsten				
Isotope	Abundance	Half-life (<i>t</i> _{1/2})	Decay mode	Product
¹⁸⁰ W	0.12%	1.8×10 ¹⁸ y	α	¹⁷⁶ Hf
¹⁸¹ W	syn	121.2 d	ε	¹⁸¹ Ta
¹⁸² W	26.50%		stable	
¹⁸³ W	14.31%		stable	
¹⁸⁴ W	30.64%		stable	
¹⁸⁵ W	syn	75.1 d	β [−]	¹⁸⁵ Re

The [free element](#) is remarkable for its robustness, especially the fact that it has the highest [melting point](#) of all known elements barring [carbon](#) (which sublimates at normal pressure), melting at 3,410 °C (6,170 °F; 3,683 K). It also has the highest [boiling point](#), at 5,930 °C (10,706 °F; 6,203 K).^[11] Its density is 19.30 grams per cubic centimetre (0.697 lb/cu in),^[12] comparable with that of [uranium](#) and [gold](#), and much higher (about 1.7 times) than that of [lead](#).^[13] Polycrystalline tungsten is an intrinsically [brittle](#)^{[14][15][16]} and [hard](#) material (under standard conditions, when uncombined), making it difficult to [work](#). However, pure single-crystalline tungsten is more [ductile](#) and can be cut with a hard-steel [hacksaw](#).^[17]

Tungsten occurs in many alloys, which have numerous applications, including incandescent [light bulb](#) filaments, [X-ray tubes](#), electrodes in [gas tungsten arc welding](#), [superalloys](#), and [radiation shielding](#). Tungsten's hardness and high [density](#) make it suitable for military applications in [penetrating projectiles](#). Tungsten compounds are often used as industrial [catalysts](#).

Tungsten is the only metal in the third [transition](#) series that is known to occur in [biomolecules](#), being found in a few species of bacteria and [archaea](#). However, tungsten interferes with [molybdenum](#) and [copper](#) metabolism and is somewhat toxic to most forms of animal life.^{[18][19]}

Characteristics

Physical properties

In its raw form, tungsten is a hard steel-grey [metal](#) that is often [brittle](#) and hard to [work](#). Purified, monocrystalline tungsten retains its [hardness](#) (which exceeds that of many steels), and becomes [malleable](#) enough that it can be worked easily.^[17] It is worked by [forging](#), [drawing](#), or [extruding](#) but it is more commonly formed by [sintering](#).

Of all metals in pure form, tungsten has the highest [melting point](#) (3,422 °C, 6,192 °F), lowest [vapor pressure](#) (at temperatures above 1,650 °C, 3,000 °F), and the highest [tensile strength](#).^[20] Although [carbon](#) remains solid at higher temperatures than tungsten, carbon [sublimes](#) at [atmospheric pressure](#) instead of melting, so it has no melting point. Tungsten has the lowest [coefficient of thermal expansion](#) of any pure metal. The low thermal expansion and high melting point and [tensile strength](#) of tungsten originate from strong [metallic bonds](#) formed between

tungsten atoms by the 5d electrons.^[21] Alloying small quantities of tungsten with [steel](#) greatly increases its [toughness](#).^[13]

Tungsten exists in two major [crystalline](#) forms: α and β . The former has a [body-centered cubic](#) structure and is the more stable form. The structure of the β phase is called [A15 cubic](#); it is [metastable](#), but can coexist with the α phase at ambient conditions owing to non-equilibrium synthesis or stabilization by impurities. Contrary to the α phase which crystallizes in isometric grains, the β form exhibits a columnar [habit](#). The α phase has one third of the [electrical resistivity](#)^[22] and a much lower [superconducting transition temperature](#) T_C relative to the β phase: ca. 0.015 K vs. 1–4 K; mixing the two phases allows obtaining intermediate T_C values.^{[23][24]} The T_C value can also be raised by [alloying](#) tungsten with another metal (e.g. 7.9 K for W-Tc).^[25] Such tungsten alloys are sometimes used in low-temperature superconducting circuits.^{[26][27][28]}

Isotopes

Naturally occurring tungsten consists of four stable [isotopes](#) (^{182}W , ^{183}W , ^{184}W , and ^{186}W) and one very long-lived radioisotope, ^{180}W . Theoretically, all five can decay into isotopes of element 72 ([hafnium](#)) by [alpha emission](#), but only ^{180}W has been observed to do so, with a half-life of $(1.8 \pm 0.2) \times 10^{18}$ years;^{[29][30]} on average, this yields about two alpha decays of ^{180}W per gram of natural tungsten per year.^[31] A rate equivalent to a [specific activity](#) of roughly 63 micro-becquerel per kilogram. This rate of decay is orders of magnitude lower than that observed in carbon or potassium as found on earth, which likewise contain small amounts of long-lived radioactive isotopes. [Bismuth](#) was long thought to be non-radioactive, but ^{209}Bi (its longest lived isotope) actually decays with a half life of 2.01×10^{19} years or about a factor 10 slower than ^{180}W . However, due to naturally occurring bismuth being 100% ^{209}Bi , its specific activity is actually higher than that of natural tungsten at 3 milli-becquerel per kilogram. The other naturally occurring isotopes of tungsten have not been observed to decay, constraining their half-lives to be at least 4×10^{21} years - if they decay at all.

Another 30 artificial [radioisotopes](#) of tungsten have been characterized, the most stable of which are ^{181}W with a half-life of 121.2 days, ^{185}W with a half-life of 75.1 days, ^{188}W with a half-life of 69.4 days, ^{178}W with a half-life of 21.6 days, and ^{187}W with a half-life of 23.72 h.^[31] All of the remaining [radioactive](#) isotopes have half-lives of less than 3 hours, and most of these have half-lives below 8 minutes.^[31] Tungsten also has 11 [meta states](#), with the most stable being $^{179\text{m}}\text{W}$ ($t_{1/2}$ 6.4 minutes).

Chemical properties

Tungsten is a mostly non-reactive element: it does not react with water, is immune to attack by most acids and bases, and does not react with oxygen or air at room temperature. At elevated temperatures (i.e., when red-hot) it reacts with oxygen to form the [trioxide](#) compound tungsten(VI), WO_3 . It will, however, react directly with fluorine (F_2) at room temperature to form [tungsten\(VI\) fluoride](#) (WF_6), a colorless gas. At around 250 °C it will react with chlorine or bromine, and under certain hot conditions will react with iodine. Finely divided tungsten is [pyrophoric](#).^{[32][33]}

The most common formal [oxidation state](#) of tungsten is +6, but it exhibits all oxidation states from -2 to +6.^{[33][34]} Tungsten typically combines with oxygen to form the yellow [tungstic oxide](#), WO_3 , which dissolves in aqueous alkaline solutions to form tungstate ions, WO_4^{2-} .

[Tungsten carbides](#) (W_2C and WC) are produced by heating powdered tungsten with carbon. W_2C is resistant to chemical attack, although it reacts strongly with [chlorine](#) to form [tungsten hexachloride](#) (WCl_6).^[13]

In aqueous solution, tungstate gives the [heteropoly acids](#) and [polyoxometalate anions](#) under neutral and acidic conditions. As [tungstate](#) is progressively treated with acid, it first yields the soluble, [metastable](#) "paratungstate A" [anion](#), $\text{W}_7\text{O}_{24}^{6-}$, which over time converts to the less soluble "paratungstate B" anion, $\text{H}_2\text{W}_{12}\text{O}_{42}^{10-}$.^[35] Further acidification produces the very soluble metatungstate anion, $\text{H}_2\text{W}_{12}\text{O}_{40}^{6-}$, after which equilibrium is reached. The metatungstate ion exists as a symmetric cluster of twelve tungsten-[oxygen octahedra](#) known as the [Keggin](#) anion. Many other polyoxometalate anions exist as metastable species. The inclusion of a different atom such as [phosphorus](#) in place of the two central [hydrogens](#) in metatungstate produces a wide variety of heteropoly acids, such as [phosphotungstic acid](#) $\text{H}_3\text{PW}_{12}\text{O}_{40}$.

Tungsten trioxide can form [intercalation](#) compounds with alkali metals. These are known as *bronzes*; an example is [sodium tungsten bronze](#).

In gaseous form, tungsten forms the diatomic species W_2 . These molecules feature a [sextuple bond](#) between tungsten atoms — the highest known bond order among [stable](#) atoms.^{[36][37]}

History

In 1781, [Carl Wilhelm Scheele](#) discovered that a new [acid](#), [tungstic acid](#), could be made from [scheelite](#) (at the time called tungsten).^{[38][39]} Scheele and [Torbern Bergman](#) suggested that it

might be possible to obtain a new metal by reducing this acid.^[40] In 1783, [José](#) and [Fausto Elhuyar](#) found an acid made from [wolframite](#) that was identical to tungstic acid. Later that year, at the [Royal Basque Society](#) in the town of [Bergara](#), Spain, the brothers succeeded in isolating tungsten by reduction of this acid with [charcoal](#), and they are credited with the discovery of the element (they called it "wolfram" or "volfram").^{[41][42][43][44][45]}

The strategic value of tungsten came to notice in the early 20th century. British authorities acted in 1912 to free the [Carrock mine](#) from the German owned Cumbrian Mining Company and, during [World War I](#), restrict German access elsewhere.^[46] In [World War II](#), tungsten played a more significant role in background political dealings. Portugal, as the main European source of the element, was [put under pressure from both sides](#), because of its deposits of wolframite ore at [Panasqueira](#). Tungsten's desirable properties such as resistance to high temperatures, its hardness and density, and its strengthening of alloys made it an important raw material for the arms industry,^{[47][48]} both as a constituent of weapons and equipment and employed in production itself, e.g., in [tungsten carbide](#) cutting tools for machining steel. Now tungsten is used in many more applications such as aircraft & motorsport ballast weights, darts, anti-vibration tooling, and sporting equipment.

Tungsten is unique amongst the elements in that it has been the subject of patent proceedings. In 1928, a US court rejected [General Electric](#)'s attempt to patent it, overturning [U.S. Patent 1,082,933](#) (<https://patents.google.com/patent/US1082933>) granted in 1913 to [William D. Coolidge](#).^{[49][50][51]}

Etymology

The name "tungsten" (which means "heavy stone" in [Swedish](#)) is used in English, French, and many other languages as the name of the element, but not in the [Nordic countries](#). "Tungsten" was the old Swedish name for the mineral [scheelite](#). "Wolfram" (or "volfram") is used in most European (especially Germanic, Spanish and Slavic) languages and is derived from the mineral [wolframite](#), which is the origin of the chemical symbol **W**.^[17] The name "wolframite" is derived from German "*wolf rahm*" ("wolf soot" or "wolf cream"), the name given to tungsten by [Johan Gottschalk Wallerius](#) in 1747. This, in turn, derives from [Latin](#) "*lupi spuma*", the name [Georg Agricola](#) used for the element in 1546, which translates into English as "wolf's froth" and is a reference to the large amounts of [tin](#) consumed by the mineral during its extraction, as though the mineral devoured it like a wolf.^[8] This naming follows a tradition of colorful names miners from the [Ore Mountains](#) would give various minerals out of a superstition that certain ones that looked as if they contained then-known valuable metals but didn't were somehow "hexed".

Cobalt (c.f. [Kobold](#)), [pitchblende](#) (c.f. German "[blenden](#)" for "to blind" or "to deceive") and [nickel](#) (c.f. "[Old Nick](#)") derive their names from the same miner's idiom.

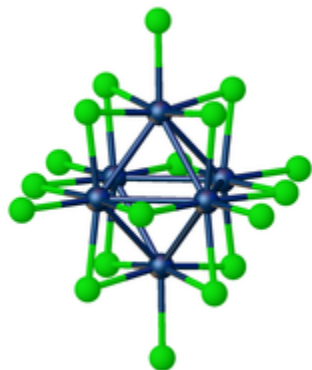
Occurrence



Wolframite mineral, with a scale in cm

Tungsten has thus far not been found in nature in its pure form.^[52] Instead, tungsten is found mainly in the minerals [wolframite](#) and [scheelite](#).^[52] Wolframite is [iron–manganese](#) tungstate $(\text{Fe,Mn})\text{WO}_4$, a solid solution of the two minerals [ferberite](#) (FeWO_4) and [hübnerite](#) (MnWO_4) , while [scheelite](#) is [calcium](#) tungstate (CaWO_4) . Other tungsten minerals range in their level of abundance from moderate to very rare, and have almost no economic value.

Chemical compounds



Structure of W_6Cl_{18} ("tungsten trichloride")

Tungsten forms chemical compounds in oxidation states from -II to VI. Higher oxidation states, always as oxides, are relevant to its terrestrial occurrence and its biological roles, mid-level oxidation states are often associated with [metal clusters](#), and very low oxidation states are typically associated with [CO complexes](#). The chemistries of tungsten and [molybdenum](#) show strong similarities to each other, as well as contrasts with their lighter congener, [chromium](#). The relative rarity of tungsten(III), for example, contrasts with the pervasiveness of the chromium(III) compounds. The highest oxidation state is seen in [tungsten\(VI\) oxide](#) (WO_3).^[53] Tungsten(VI) oxide is soluble in aqueous [base](#), forming tungstate (WO_4^{2-}). This [oxyanion](#) condenses at lower [pH](#) values, forming [polyoxotungstates](#).^[54]

The broad range of [oxidation states](#) of tungsten is reflected in its various chlorides.^[53]

- [Tungsten\(II\) chloride](#), which exists as the hexamer W_6Cl_{12}
- [Tungsten\(III\) chloride](#), which exists as the hexamer W_6Cl_{18}
- [Tungsten\(IV\) chloride](#), WCl_4 , a black solid, which adopts a polymeric structure.
- [Tungsten\(V\) chloride](#) WCl_5 , a black solid which adopts a dimeric structure.
- [Tungsten\(VI\) chloride](#) WCl_6 , which contrasts with the instability of $MoCl_6$.

[Organotungsten compounds](#) are numerous and also span a range of oxidation states. Notable examples include the trigonal prismatic $W(CH_3)_6$ and octahedral $W(CO)_6$.

Production



Tungsten mining in [Rwanda](#) forms an important part of the country's economy.

Reserves

The world's reserves of tungsten are 3,200,000 tonnes; they are mostly located in [China](#) (1,800,000 t), [Canada](#) (290,000 t),^[55] [Russia](#) (160,000 t), [Vietnam](#) (95,000 t) and [Bolivia](#). As of 2017, China, Vietnam and Russia are the leading suppliers with 79,000, 7,200 and 3,100 tonnes, respectively. Canada had ceased production in late 2015 due to the closure of its sole tungsten mine. Meanwhile, Vietnam had significantly increased its output in the 2010s, owing to the major optimization of its domestic refining operations, and overtook Russia and Bolivia.^[56]

China remains the world's leader not only in production, but also in export and consumption of tungsten products. Tungsten production is gradually increasing outside China because of the rising demand. Meanwhile, its supply by China is strictly regulated by the Chinese Government, which fights illegal mining and excessive pollution originating from mining and refining processes.^[57]

There is a large deposit of tungsten ore on the edge of [Dartmoor](#) in the [United Kingdom](#), which was exploited during [World War I](#) and [World War II](#) as the [Hemerdon Mine](#). Following increases in tungsten prices, this mine was reactivated in 2014,^[58] but ceased activities in 2018.^[59]

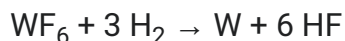
Within the [EU](#), the [Austrian](#) Felbertal scheelite deposit is one of the few producing tungsten mines.^[60] [Portugal](#) is one of Europe's main tungsten producers, with 121 kt of contained tungsten in mineral concentrates from 1910 to 2020, accounting for roughly 3.3% of the global production.^[61]

Tungsten is considered to be a [conflict mineral](#) due to the unethical mining practices observed in the [Democratic Republic of the Congo](#).^{[62][63]}

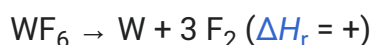
Extraction

Tungsten is extracted from its ores in several stages. The ore is eventually converted to [tungsten\(VI\) oxide](#) (WO_3), which is heated with [hydrogen](#) or carbon to produce powdered tungsten.^[40] Because of tungsten's high melting point, it is not commercially feasible to cast tungsten [ingots](#). Instead, powdered tungsten is mixed with small amounts of powdered nickel or other metals, and [sintered](#). During the sintering process, the nickel diffuses into the tungsten, producing an alloy.

Tungsten can also be extracted by hydrogen reduction of WF_6 :

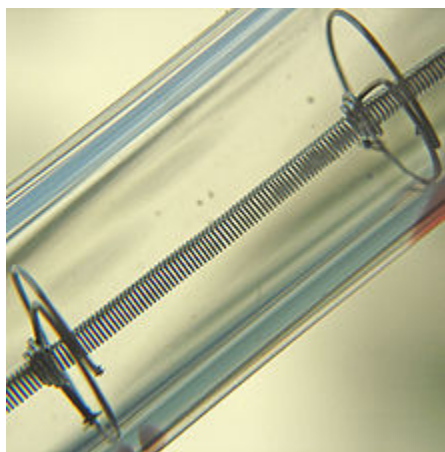


or [pyrolytic decomposition](#):^[64]



Tungsten is not traded as a futures contract and cannot be tracked on exchanges like the [London Metal Exchange](#). The tungsten industry often uses independent pricing references such as [Argus Media](#) or [Metal Bulletin](#) as a basis for contracts.^[65] The prices are usually quoted for tungsten concentrate or WO_3 .^[56]

Applications





Tungsten carbide jewelry

Approximately half of the tungsten is consumed for the production of hard materials – namely **tungsten carbide** – with the remaining major use being in alloys and steels. Less than 10% is used in other **chemical compounds**.^[66] Because of the high ductile-brittle transition temperature of tungsten, its products are conventionally manufactured through **powder metallurgy**, **spark plasma sintering**, **chemical vapor deposition**, **hot isostatic pressing**, and **thermoplastic** routes. A more flexible manufacturing alternative is **selective laser melting**, which is a form of 3D printing and allows creating complex three-dimensional shapes.^[67]

Industrial

Tungsten is mainly used in the production of hard materials based on **tungsten carbide** (WC), one of the hardest **carbides**. WC is an efficient **electrical conductor**, but W_2C is less so. WC is used to make wear-resistant **abrasives**, and "carbide" cutting tools such as knives, drills, **circular saws**, **dies**, **milling** and **turning** tools used by the metalworking, woodworking, **mining**, **petroleum** and construction industries.^[13] Carbide tooling is actually a ceramic/metal composite, where metallic cobalt acts as a binding (**matrix**) **material** to hold the WC particles in place. This type of industrial use accounts for about 60% of current tungsten consumption.^[68]

The **jewelry** industry makes rings of sintered **tungsten carbide**, tungsten carbide/metal composites, and also metallic tungsten.^[69] WC/metal composite rings use nickel as the metal matrix in place of **cobalt** because it takes a higher luster when polished. Sometimes

manufacturers or retailers refer to [tungsten carbide](#) as a metal, but it is a [ceramic](#).^[70] Because of tungsten carbide's hardness, rings made of this material are extremely abrasion resistant, and will hold a burnished finish longer than rings made of metallic tungsten. Tungsten carbide rings are brittle, however, and may crack under a sharp blow.^[71]

Alloys

The hardness and heat resistance of tungsten can contribute to useful [alloys](#). A good example is [high-speed steel](#), which can contain as much as 18% tungsten.^[72] Tungsten's high melting point makes tungsten a good material for applications like [rocket nozzles](#), for example in the [UGM-27 Polaris submarine-launched ballistic missile](#).^[73] Tungsten alloys are used in a wide range of applications, including the aerospace and automotive industries and radiation shielding.^[74] [Superalloys](#) containing tungsten, such as [Hastelloy](#) and [Stellite](#), are used in [turbine](#) blades and wear-resistant parts and coatings.

Tungsten's heat resistance makes it useful in [arc welding](#) applications when combined with another highly-conductive metal such as silver or copper. The silver or copper provides the necessary conductivity and the tungsten allows the welding rod to withstand the high temperatures of the arc welding environment.^[75]

Permanent magnets

Quenched (martensitic) tungsten steel (approx. 5.5% to 7.0% W with 0.5% to 0.7% C) was used for making hard permanent magnets, due to its high [remanence](#) and [coercivity](#), as noted by [John Hopkinson](#) (1849–1898) as early as 1886. The magnetic properties of a metal or an alloy are very sensitive to microstructure. For example, while the element tungsten is not ferromagnetic (but [iron](#) is), when it is present in steel in these proportions, it stabilizes the [martensite](#) phase, which has greater ferromagnetism than the [ferrite \(iron\)](#) phase due to its greater resistance to [magnetic domain wall motion](#).

Military

Tungsten, usually alloyed with [nickel](#), [iron](#), or [cobalt](#) to form heavy alloys, is used in [kinetic energy penetrators](#) as an alternative to [depleted uranium](#), in applications where uranium's [radioactivity](#) is problematic even in depleted form, or where uranium's additional [pyrophoric](#) properties are not desired (for example, in ordinary small arms bullets designed to penetrate body armor). Similarly, tungsten alloys have also been used in [shells](#), [grenades](#), and [missiles](#), to

create supersonic shrapnel. Germany used tungsten during World War II to produce shells for anti-tank gun designs using the Gerlich [squeeze bore](#) principle to achieve very high muzzle velocity and enhanced armor penetration from comparatively small caliber and light weight field artillery. The weapons were highly effective but a shortage of tungsten used in the shell core, caused in part by the [Wolfram Crisis](#), limited their use.

Tungsten has also been used in [Dense inert metal explosives](#), which use it as dense powder to reduce collateral damage while increasing the lethality of explosives within a small radius.^[76]

Chemical applications

[Tungsten\(IV\) sulfide](#) is a high temperature [lubricant](#) and is a component of catalysts for [hydrodesulfurization](#).^[77] MoS_2 is more commonly used for such applications.^[78]

Tungsten [oxides](#) are used in [ceramic](#) glazes and [calcium/magnesium](#) tungstates are used widely in [fluorescent lighting](#). Crystal [tungstates](#) are used as [scintillation detectors](#) in [nuclear physics](#) and [nuclear medicine](#). Other salts that contain tungsten are used in the chemical and [tanning](#) industries.^[20] Tungsten oxide (WO_3) is incorporated into [selective catalytic reduction](#) (SCR) catalysts found in coal-fired power plants. These catalysts convert [nitrogen oxides](#) (NO_x) to nitrogen (N_2) and water (H_2O) using ammonia (NH_3). The tungsten oxide helps with the physical strength of the catalyst and extends catalyst life.^[79] Tungsten containing catalysts are promising for epoxidation,^[80] oxidation,^[81] and hydrogenolysis reactions.^[82] Tungsten heteropoly acids are key component of multifunctional catalysts.^[83] Tungstates can be used as photocatalyst,^[84] while the tungsten sulfide as electrocatalyst.^[85]

Niche uses

Applications requiring its high density include weights, [counterweights](#), ballast keels for yachts, tail ballast for commercial aircraft, rotor weights for civil and military helicopters, and as ballast in race cars for [NASCAR](#) and [Formula One](#).^[86] Being slightly less than twice the density, Tungsten is seen as an alternative (albeit more expensive) to lead [fishing sinkers](#). [Depleted uranium](#) is also used for these purposes, due to similarly high density. Seventy-five-kg blocks of tungsten were used as "cruise balance mass devices" on the entry vehicle portion of the 2012 [Mars Science Laboratory](#) spacecraft. It is an ideal material to use as a [dolly](#) for [riveting](#), where the mass necessary for good results can be achieved in a compact bar. High-density alloys of tungsten with nickel, copper or iron are used in high-quality [darts](#)^[87] (to allow for a smaller diameter and thus tighter groupings) or for [artificial flies](#) (tungsten beads allow the fly to sink

rapidly). Tungsten is also used as a heavy bolt to lower the rate of fire of the [SWD M11/9](#) sub-machine gun from 1300 RPM to 700 RPM. Tungsten has seen use recently in nozzles for [3D printing](#); the high wear resistance and thermal conductivity of tungsten carbide improves the printing of abrasive filaments.^[88] Some [cello](#) C strings are wound with tungsten. The extra density gives this string more projection and often cellists will buy just this string and use it with three strings from a different set.^[89] Tungsten is used as an absorber on the electron telescope on the [Cosmic Ray System](#) of the two [Voyager spacecraft](#).^[90]

Gold substitution

Its density, similar to that of gold, allows tungsten to be used in jewelry as an alternative to [gold](#) or [platinum](#).^{[17][91]} Metallic tungsten is [hypoallergenic](#), and is harder than gold alloys (though not as hard as tungsten carbide), making it useful for [rings](#) that will resist scratching, especially in designs with a [brushed finish](#).

Because the density is so similar to that of gold (tungsten is only 0.36% less dense), and its price of the order of one-thousandth, tungsten can also be used in [counterfeiting](#) of [gold bars](#), such as by plating a tungsten bar with gold,^{[92][93][94]} which has been observed since the 1980s,^[95] or taking an existing gold bar, drilling holes, and replacing the removed gold with tungsten rods.^[96] The densities are not exactly the same, and other properties of gold and tungsten differ, but gold-plated tungsten will pass superficial tests.^[92]

Gold-plated tungsten is available commercially from China (the main source of tungsten), both in jewelry and as bars.^[97]

Electronics

Because it retains its strength at high temperatures and has a high [melting point](#), elemental tungsten is used in many high-temperature applications,^[98] such as [incandescent light bulb](#), [cathode-ray tube](#), and [vacuum tube](#) filaments, [heating elements](#), and [rocket engine](#) nozzles.^[17] Its high melting point also makes tungsten suitable for aerospace and high-temperature uses such as electrical, heating, and welding applications, notably in the [gas tungsten arc welding](#) process (also called tungsten inert gas (TIG) welding).^[99]



Tungsten electrode used in a [gas tungsten arc welding](#) torch

Because of its conductive properties and relative chemical inertness, tungsten is also used in [electrodes](#), and in the emitter tips in electron-beam instruments that use [field emission guns](#), such as [electron microscopes](#). In electronics, tungsten is used as an interconnect material in [integrated circuits](#), between the [silicon dioxide dielectric](#) material and the transistors. It is used in metallic films, which replace the wiring used in conventional electronics with a coat of tungsten (or [molybdenum](#)) on [silicon](#).^[64]

The electronic structure of tungsten makes it one of the main sources for [X-ray](#) targets,^{[100][101]} and also for shielding from high-energy radiations (such as in the [radiopharmaceutical](#) industry for shielding radioactive samples of [FDG](#)). It is also used in gamma imaging as a material from which coded apertures are made, due to its excellent shielding properties. Tungsten powder is used as a filler material in [plastic](#) composites, which are used as a nontoxic substitute for [lead](#) in [bullets](#), [shot](#), and radiation shields. Since this element's thermal expansion is similar to [borosilicate glass](#), it is used for making glass-to-metal seals.^[20] In addition to its high melting point, when tungsten is doped with potassium, it leads to an increased shape stability (compared with non-doped tungsten). This ensures that the filament does not sag, and no undesired changes occur.^[102]

Nanowires

Through top-down [nanofabrication](#) processes, tungsten [nanowires](#) have been fabricated and studied since 2002.^[103] Due to a particularly high surface to volume ratio, the formation of a surface oxide layer and the single crystal nature of such material, the mechanical properties differ fundamentally from those of bulk tungsten.^[104] Such tungsten nanowires have potential applications in [nanoelectronics](#) and importantly as pH probes and gas sensors.^[105] In similarity to [silicon nanowires](#), tungsten nanowires are frequently produced from a bulk tungsten

precursor followed by a [thermal oxidation](#) step to control morphology in terms of length and aspect ratio.^[106] Using the [Deal–Grove model](#) it is possible to predict the oxidation kinetics of nanowires fabricated through such thermal oxidation processing.^[107]

Fusion power

Due to its high melting point and good erosion resistance, tungsten is a lead candidate for the most exposed sections of the plasma-facing inner wall of [nuclear fusion reactors](#). It will be used as the [plasma-facing material](#) of the [divertor](#) in the [ITER](#) reactor,^[108] and is currently in use in the [JET](#) test reactor.

Biological role

Tungsten, at atomic number $Z = 74$, is the heaviest element known to be biologically functional. It is used by some bacteria and [archaea](#),^[109] but not in [eukaryotes](#). For example, [enzymes](#) called [oxidoreductases](#) use tungsten similarly to [molybdenum](#) by using it in a tungsten-[pterin](#) complex with [molybdopterin](#) (molybdopterin, despite its name, does not contain molybdenum, but may complex with either molybdenum or tungsten in use by living organisms). Tungsten-using enzymes typically reduce carboxylic acids to aldehydes.^[110] The tungsten oxidoreductases may also catalyse oxidations. The first tungsten-requiring enzyme to be discovered also requires selenium, and in this case the tungsten-selenium pair may function analogously to the molybdenum-sulfur pairing of some molybdopterin-requiring enzymes.^[111] One of the enzymes in the oxidoreductase family which sometimes employ tungsten (bacterial [formate dehydrogenase](#) H) is known to use a selenium-molybdenum version of molybdopterin.^[112] [Acetylene hydratase](#) is an unusual [metalloenzyme](#) in that it catalyzes a hydration reaction. Two reaction mechanisms have been proposed, in one of which there is a direct interaction between the tungsten atom and the $C\equiv C$ triple bond.^[113] Although a tungsten-containing [xanthine dehydrogenase](#) from bacteria has been found to contain tungsten-molybdopterin and also non-protein bound selenium, a tungsten-selenium molybdopterin complex has not been definitively described.^[114]

In soil, tungsten metal oxidizes to the [tungstate](#) anion. It can be selectively or non-selectively imported by some [prokaryotic organisms](#) and may substitute for [molybdate](#) in certain [enzymes](#). Its effect on the action of these enzymes is in some cases inhibitory and in others positive.^[115] The soil's chemistry determines how the tungsten polymerizes; [alkaline](#) soils cause monomeric tungstates; [acidic](#) soils cause polymeric tungstates.^[116]

[Sodium tungstate](#) and [lead](#) have been studied for their effect on [earthworms](#). Lead was found to be lethal at low levels and sodium tungstate was much less toxic, but the tungstate completely inhibited their [reproductive ability](#).^[117]

Tungsten has been studied as a biological copper metabolic [antagonist](#), in a role similar to the action of molybdenum. It has been found that [tetrathiotungstate](#) salts may be used as biological copper [chelation](#) chemicals, similar to the [tetrathiomolybdates](#).^[118]

In archaea

Tungsten is essential for some archaea. The following tungsten-utilizing enzymes are known:

- [Aldehyde ferredoxin oxidoreductase](#) (AOR) in *Thermococcus* strain ES-1
- Formaldehyde ferredoxin oxidoreductase (FOR) in *Thermococcus litoralis*
- [Glyceraldehyde-3-phosphate ferredoxin oxidoreductase](#) (GAPOR) in *Pyrococcus furiosus*

A *wtp* system is known to selectively transport tungsten in archaea:

- WtpA is tungsten-binding protein of [ABC family of transporters](#)
- WtpB is a [permease](#)
- WtpC is [ATPase](#)^[119]

Health factors

Because tungsten is a rare metal^[120] and its compounds are generally inert, the effects of tungsten on the environment are limited.^[121] The abundance of tungsten in the Earth's crust is thought to be about 1.5 parts per million. It is one of the rarer elements.

It was at first believed to be relatively inert and an only slightly toxic metal, but beginning in the year 2000, the risk presented by tungsten alloys, its dusts and particulates to induce cancer and several other adverse effects in animals as well as humans has been highlighted from in vitro and in vivo experiments.^{[122][123]} The [median lethal dose](#) LD₅₀ depends strongly on the animal and the method of administration and varies between 59 mg/kg (intravenous, rabbits)^{[124][125]} and 5000 mg/kg (tungsten metal powder, [intraperitoneal](#), rats).^{[126][127]}

People can be exposed to tungsten in the workplace by breathing it in, swallowing it, skin contact, and eye contact. The [National Institute for Occupational Safety and Health](#) (NIOSH) has

set a [recommended exposure limit](#) (REL) of 5 mg/m³ over an 8-hour workday and a short term limit of 10 mg/m³.^[128]

See also

- [Field emission gun](#)
- [Tungsten oxide](#)
- [List of chemical elements name etymologies](#)
- [List of chemical elements naming controversies](#)

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